NOVAE ON VENUS: GEOLOGY, CLASSIFICATION AND SCENARIOS OF EVOLUTION. A. S. Krassilnikov[1, 2] and J. W. Head[2], [1]Vernadsky Institute, 119991, Moscow, Russia, kras@geokhi.ru, [2]Department of Geological Science, Brown University, Providence, RI, 02912, USA.

INTRODUCTION. Novae are *"radially fractured centers"* on the venusian surface 100-300 km in diameter [1-4]. Dense radial fracturing and upraised topography are common for them [2-6], massive volcanism is connected with some novae [3,4]. We studied the complete set of novae (64 structures) from the *"Catalog of volcanic structures of Venus"* [4]. Novae are interpreted to be the result of updoming and fracturing of the surface due to interaction of mantle diapirs with the lithosphere [2,7-9]. There are a few geological [7-9], numerical [2,10,11] and analog [12,13] models of novae formation. Our goals were: **1)** To study the topography and geology of all novae and their surroundings. **2)** To classify novae by their topography. **3)** To study the relationship of novae with rift zones [14-16]. **4)** To study the period of novae activity relative to regional plains with wrinkle ridges (Pwr), which can be used as stratigraphic marker [17,18]. **5)** To create scenarios of novae evolution on the basis of our observations, using models of novae formation [2,7-13] and mechanisms of radial dike swarm emplacement [19,20], volcanic construction spreading [21,22] and mantle diapirism [23,24]. We used the *"Magellan"* GTDR, C1 and F-MIDR data for analysis included detail geological mapping.

KEY OBSERVATIONS OF NOVAE.

1. Radial fracturing. Dense radial fracturing (mostly of more than one generation) is usual for all novae. Fracture to fracture spacing systematically increases from older generations to younger. Usually two generations are observed, which are characterized by straight long extensional fractures and narrow graben mostly located in the central elevated parts and on flanks of novae. Part of the fracturing extends away from the nova rises for hundreds of kilometers. In many cases the youngest fracturing is the source of lava flows, which in some cases emerge at the same elevation on nova slopes; older generations are usually observed as kipukas embayed by younger material. The distribution of fractures of numerous novae is asymmetric, mostly bilateral.

2. Classification. The topographic shape was used as the basis of classification because novae have wide varieties of sets of tectonic structures and a smaller number of characteristic topographic shapes. Studied novae for which the topography data are available (62) could be subdivided into 4 classes each characterized by a specific topographic profile. Some of novae show topographic characteristics transitional from one class to others. We put each of these in the class that was defined by their most prominent feature.

1) Upraised novae (16 novae, 26% of studied) have cone- or dome-like topographic profile. The central parts are elevated above the flanks for heights from several hundreds of meters up to 2-3 km. Some of the novae have concentric compressional and/or extensional structures.

2) Annular novae (16 novae, 26%) have an elevated central part and elevated concentric annulus. Two subtypes of them are observed: **a)** First has radial extensional fracturing in the central parts and concentric compressional structures at nova annulae and periphery. Graben and normal faults represent radial fracturing and ridges represent concentric compressional structures. The youngest radial structures are usually younger than the concentric ones. **b)** Second has radial extensional fracturing in the central parts and in the annulae of novae and concentric extensional fracturing in the annulae. Graben and normal faults represent radial and concentric fracturing. Concentric fracturing is usually younger than the radial.

3) Flat and negative novae (15 novae, 24%) with flat, irregular shapes; some of these have negative relief. Flat novae have a small number of concentric structures, while negative have concentric extensional structures.

4) Plateau-like novae (15 novae, 24%) have plateau-like shape or transitional to it. All these novae are located in rifts, and most of them have concentric graben and normal fault systems apparently formed under the influence of the rift. Three types of relationship of nova and rift are observed: ***a)*** *Nova predates rift formation.* Radial fracturing is older than rift fracturing and its orientation doesn't depend on rift strike. ***b)*** *Nova forms simultaneously with rift evolution.* Radial fracturing is simultaneous with rift fracturing, its orientation depends on rift strike – on the flanks of the nova fractures became parallel to the rift. ***c)*** *Nova postdates rift activity.* Radial fracturing is younger than rift fracturing, its orientation doesn't depend on rift strike.

3. Location on planet. Novae are located mostly in areas of volcanic rises and rifts and are clustered in the Beta-Atla-Themis triangle [3,4]. A small number of novae are located on the lowlands without any connection with other regional volcanic-tectonic structures like rifts, volcanic rises or coronae.

4. Relationship with rifts and associated volcanism. Most novae show an association with rifts (52%) and display the following relationships: **1)** Rift doesn't have influence on topography of upraised, annular, flat and negative novae. **2)** Rift has influence on the topography of plateau-like novae; rift troughs surround novae constructions and form their shape. Most of volcanic activity of novae is seen in lobate lava outflows, which are usual both for novae which are located inside and outside of rifts. With some novae small shield volcanoes and their clusters are connected. Large amounts of volcanism is common for upraised, annular and plateau-like novae. No clear connection is observed between the rate and style of volcanism and the position of the nova within or outside of the rifts.

5. Period of activity. Part of the novae (40.3%) began to form before Pwr emplacement, 11.3% completed their activity before Pwr formation, and 88.7% of the novae were active after Pwr emplacement.

6. Stratigraphic sequence. In all local areas studied the sequence of geological units is similar, thus our analysis supports model of regional and global stratigraphy [17,18].

DISCUSSION AND CONCLUSIONS.

1. Novae classification. Four classes were subdivided: 1) upraised novae; 2) annular novae; 3) flat and negative novae; 4) plateau-like novae.

2. Scenarios of novae formation. We suggest scenarios or evolutionary sequences of novae classes formation depending on the following factors: **1)** the depth of the neutral buoyancy level of the uplifting mantle diapir (n_0^d); **2)** the rheological characteristics of the part of the lithosphere which the evolving diapir influences, on the upper brittle part

or the visco-plastic lower part of the lithosphere; an important factor is the thickness of upper brittle part of the lithosphere; **3)** whether or not visco-plastic material of lower lithosphere above diapir spreads; **4)** the character of the influence of regional stress and rifts. We distinguished two geodynamic conditions of novae formation - outside and within rifts.

2.1. Formation of novae outside of rift.

1st evolutionary sequence: well-upraised => annular subtype-1. *Well-upraised:* **1)** Diapir influences the lower visco-plastic part of the lithosphere trying to reach its n_0^d, which is rather shallow to produce prominent rise on the surface [2,7-13]. **2)** Partial melting in diapir head occurs due to adiabatic decompression [23,24], magmatic reservoir forms and produces radial dike swarms, which create radial fracturing and occur along the neutral buoyancy level of the reservoir [19,20]. Regional stress influences the distribution of radial patterns. **3)** Volcanism connected with reservoir occurs, formation of lava flows is connected with dike emplacement. **4)** Beginning of gravitational relaxation of the rise takes place due to diapir cooling and flattening, which leads to the start of subsidence of the surface [2,7-11] and pressure loss inside the reservoir, results in increase of radial fracturing spacing [19,20]. *Annular (subtype-1):* **5)** Following relaxation of the rise, diapir cools and flattens, surface subsides [2,7-11]. **6)** Massive volcanism connected with magmatic reservoir occurs peaking after beginning of relaxation [23,24]. **7)** Lateral spreading of the diapir and lower visco-plastic part of the lithosphere takes place [2,8-13]. Concentric annulus and compressional structures form due to lithostatic pressure of the rise, its gravitational spreading, lateral pressure of flattening diapir and gravitational sliding on rise slopes [2,10-13,21,22]. Formation of concentric compressional structures is enhanced by small thickness of upper brittle layer of the lithosphere [12,13]. Youngest radial fracturing forms due to radial compression [2,10-13]. **8)** Complete relaxation of lithosphere relative to lithospheric isostatic equilibrium (n_0^l). *Summary:* Diapir influences the lower visco-plastic part of the lithosphere, thickness of upper brittle part of the lithosphere is rather small, n_0^d position is rather shallow.

2nd evolutionary sequence: well-upraised => annular subtype-2. *Well-upraised:* Formation is the same described above. *Annular (subtype-2).* The same with formation of annular novae of subtype-1 with following modification: plastic bend at the periphery of nova forms annulus due to lithostatic pressure of the rise [12,13]; that leads to extensional structure formation in annulus by relaxation. Their formation is enhanced by rather large thickness of the upper brittle part of the lithosphere [12,13]. *Summary:* Diapir influences the lower visco-plastic part of the lithosphere, thickness of upper brittle part of the lithosphere is rather large, n_0^d position is rather shallow.

3rd evolutionary sequence: low-upraised => flat: *Low-upraised:* The same as well-upraised novae formation with the following modification: **a)** n_0^d is rather deep to produce low prominent rise [2,7-13], **b)** low volcanic activity due to deep n_0^d and magmatic reservoir [23,24]. *Flat:* The same as annular novae formation with following modification: **a)** rare concentric structures form and complete flattening of the surface happens because of low relief of uplift stage [12,13], **b)** small amount of volcanism due to deep n_0^d and magmatic reservoir [23,24]. *Summary:* Diapir influences the lower visco-plastic part of the lithosphere, thickness of upper brittle part might be rather small as well as rather large, n_0^d position is rather deep.

4th evolutionary sequence: upraised => negative: *Upraised:* The same as low- or well-upraised, but here diapir penetrates lower visco-plastic part of the lithosphere and influences the upper brittle part essentially thinning the lithosphere. *Negative:* The same with flat novae with following modification: depression is forming with extensional structures on its bend by complete relaxation relative to n_0^l because of lithosphere thinning by updoming. *Summary:* Diapir penetrates lower visco-plastic part of the lithosphere and influences the upper brittle, thickness of brittle part is large, n_0^d position might be rather shallow as well as rather deep.

2.2. Formation of novae within rift.

1) Nova predates rift. Novae are recycled by rift, therefore, any nova might be recycled by rift. Rift fracturing forms due to passive regional tension and outlines more competent nova construction because of thickening of the lithosphere due to integration there of more rigid cold and solid diapir formed by nova.

2) Nova forms simultaneously with rift. Formation of nova is connected with most uplifted inhomogeneity of hot material along the rift, which produces rise surrounded by rift valleys. Nova forms the same as upraised, but at the periphery of nova fracture strike conforms to rift as result of regional tension. In rift zones lithosphere is tectonically and thermally thinned, which leads to more active pressure release melting and massive volcanism [23,24]. Rift fracturing and troughs form due to passive regional tension and outline nova rise.

3) Nova postdates rift. Its formation is the same as upraised novae inheriting previously formed rift troughs.

3. Period of novae activity. It was shown that novae have multiple stages and are long-lived structures [5,6]. In contrast to novae, coronae activity was greatest before Pwr formation [25]. This may be evidence for thickening of the lithosphere with time, what has been predicted [26,27]. We also showed that formation of novae not in all cases leads to formation of corona-like structures, and not all coronae were formed by gravitational relaxation of novae.

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